Harnessing the power of water:

Building a Hydropower plant

Photo courtesy of Jonathan Matthews

A Brief Introduction

- Hydroelectricity examples:
  - Irafoss- Iceland
  - Dinorwig- United Kingdom

Irafoss

- Hydroelectric power plant in Iceland.
- One of three power stations located along the Sog.
- The main purpose was to provide electricity for the capital of Reykjavik.

A look from above…

Some Specifics

- Harnesses both the Irafoss and Kistufuss Falls on the lower Sog.
- Combined has a head of 38m.
- Online in 1953 using 2- 15.5 MW turbines.
- 1963 expansion added a third turbine with 16.7 MW capacity.

Electric Mountain at Dinorwig

- A pump-storage facility.
- Two reservoirs at different altitudes are required.
- Water from the higher reservoir is released.
- Energy is created.
- Water is then pumped back to the upper reservoir.

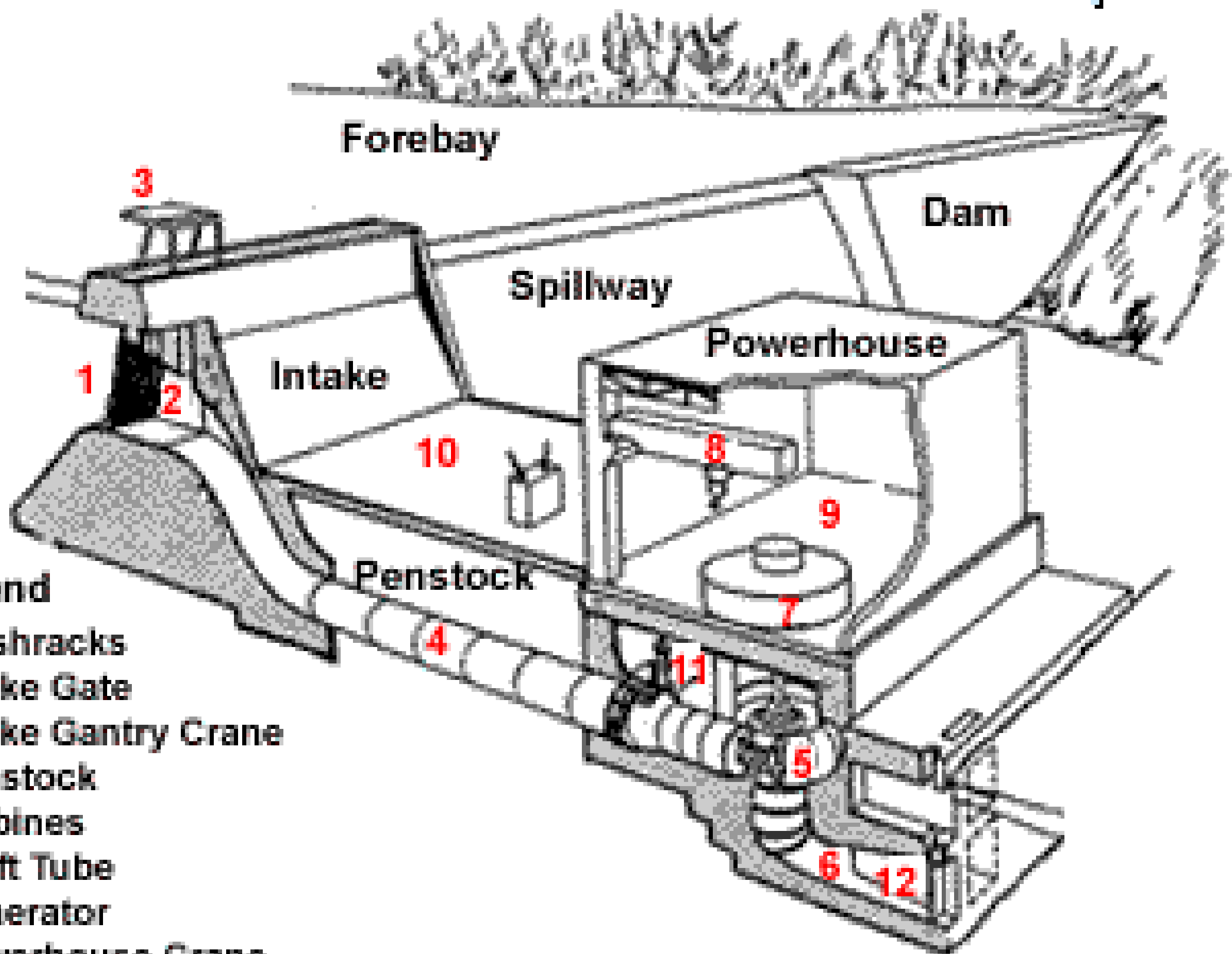
Some specifics

- 1320MW of power can be produced in 12 seconds when there is sudden surge in demand.
- Off-peak powers the return of the water to the upper reservoir.

Hydroelectric Power

- There are different sizes:
  - Micro: <100kW, typical supply for 1-2 houses
  - Mini: 100kW-1MW, isolated community, small factory
  - Small: 1MW-30MW, typical supply to regional grid

Schematic of medium-head plant



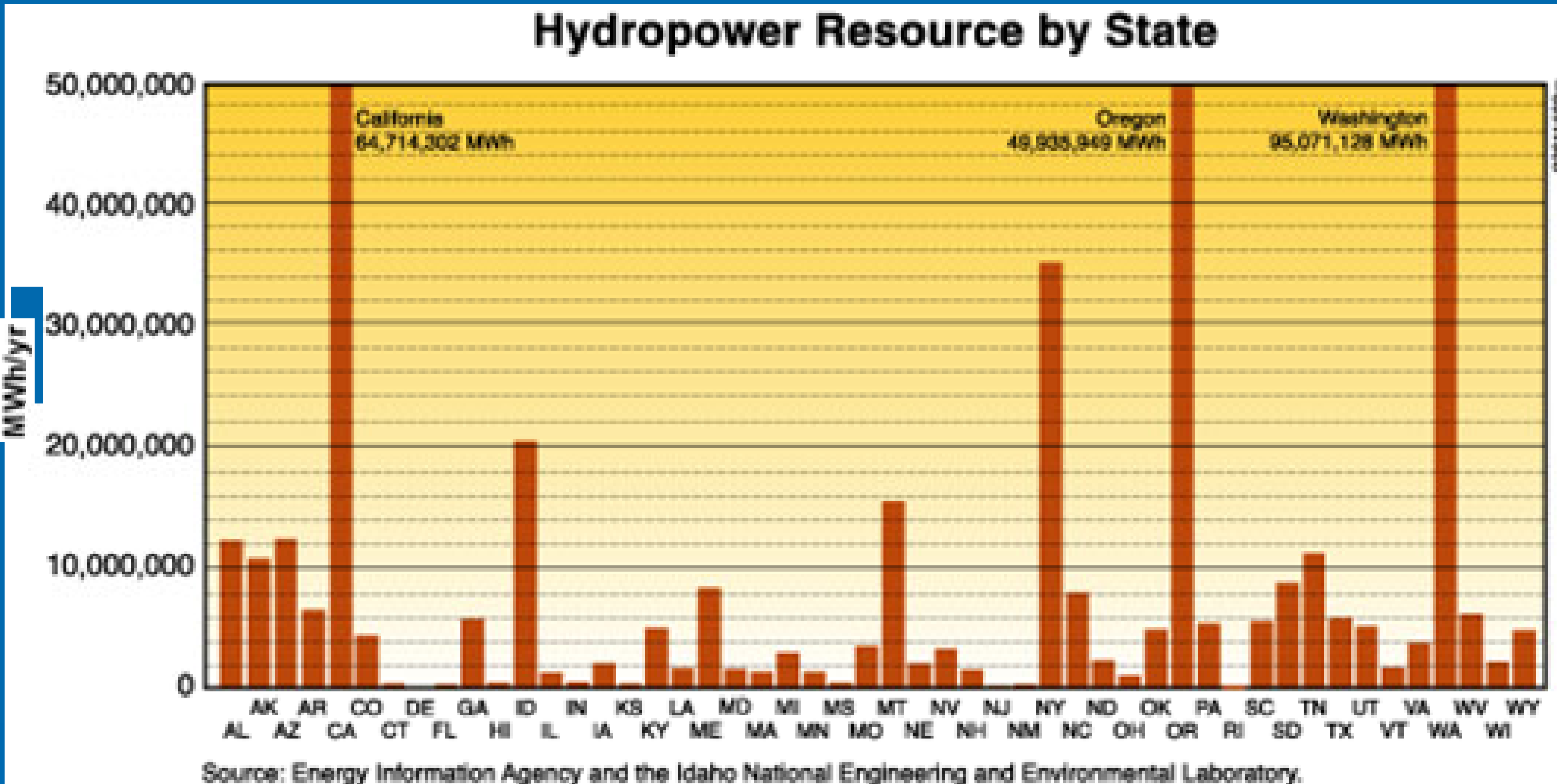
Legend

1 Trashracks
2 Intake Gate
3 Intake Gantry Crane
4 Penstock
5 Turbines
6 Draft Tube
7 Generator
8 Powerhouse Crane
9 Repair bay
10 Switchyard
11 Shutoff Valve
12 Draft Tube Stoplogs

(Source: Shawinigan Consultants Ltd.)

Hydroelectric Power Potential in the USA

- Based on environmental, legal, and institutional constraints there are 5,677 sites that have a total undeveloped capacity of about 30,000MW
- Hydroelectric power accounts for about 10% of the energy produced in the USA



→ Pennsylvania Possibilities: 5,525,646 MWh of electricity annually

→ Only be about 3% of all electricity generated in PA.

http://www.eere.energy.gov/state_energy/tech_hydropower.cfm?state=PA

Hydropower potential in Pennsylvania

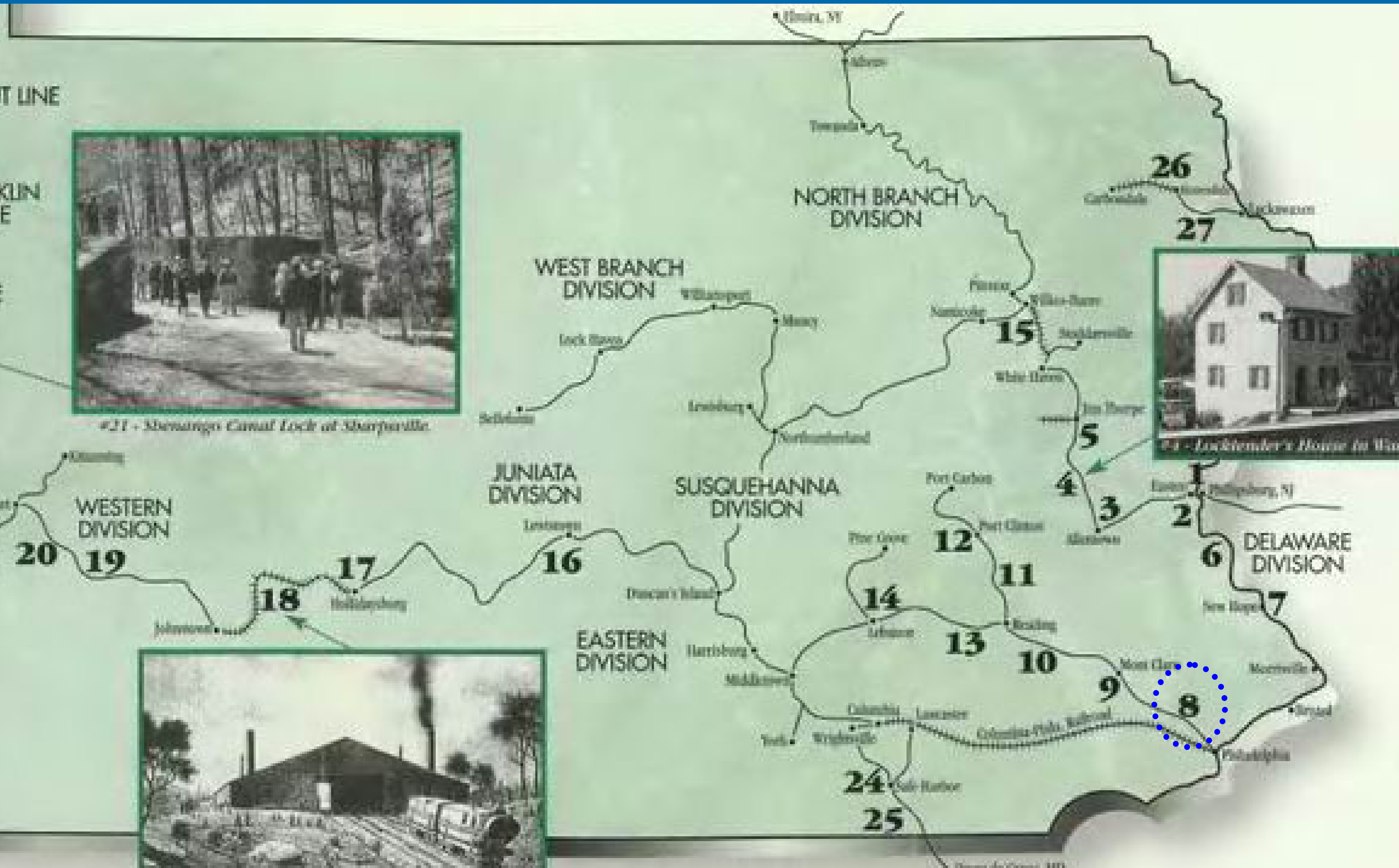
State	Category	Number Of Projects	Name Plate Capacity (MW)	HES Adjusted Capacity (MW)
Pennsylvania	With Power	5	207	105
	W/O Power	67	310	187
	Undeveloped	32	1,701	411
	State Total	104	2,218	703

From the U.S. Hydropower Resource Assessment Final Report

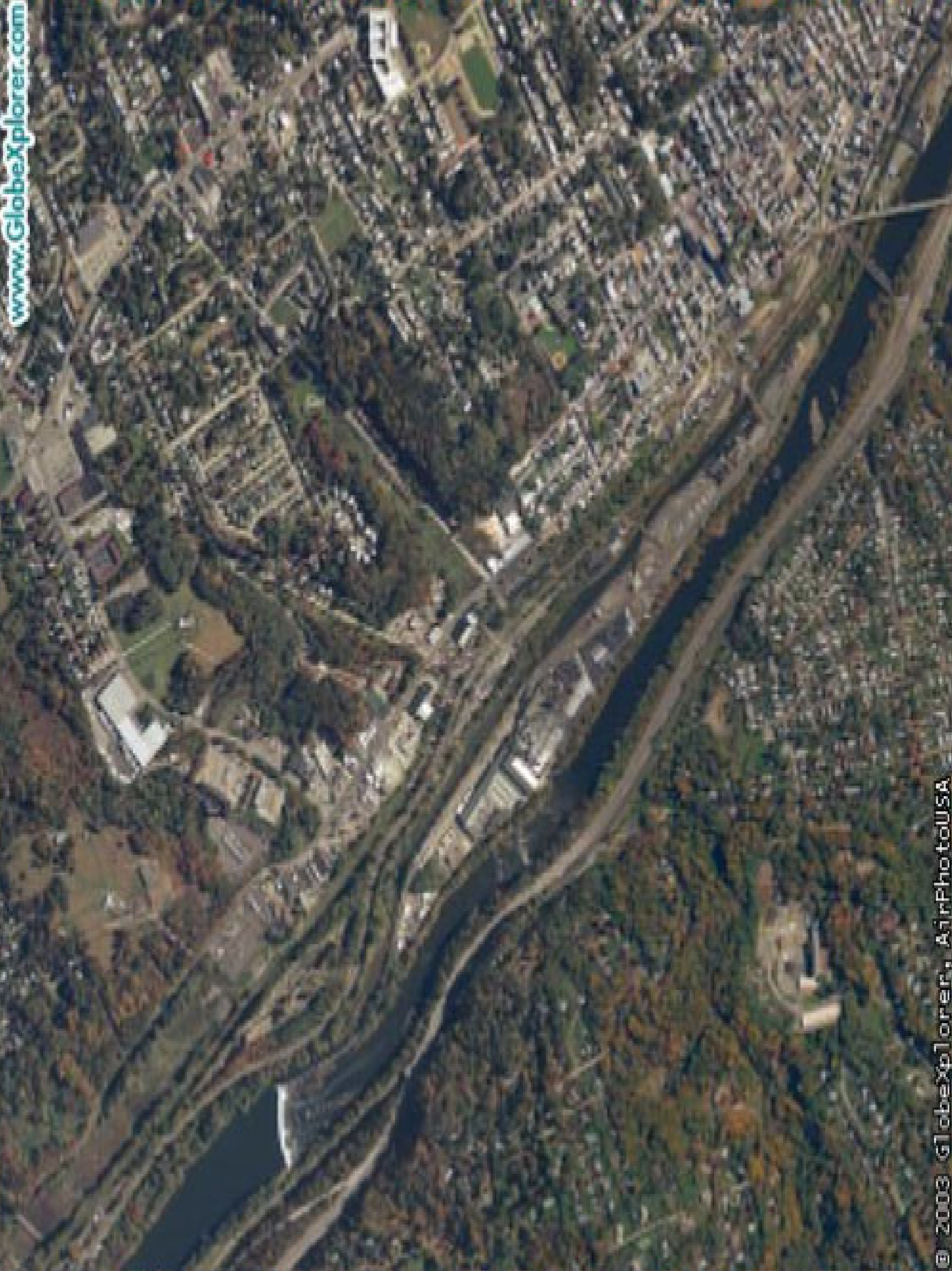
Flat Rock Dam

- Location
  - Manayunk, PA
  - Philadelphia County
  - Delaware River Basin
  - On the Schuylkill River
- History
  - Canal & dam first built in 1819
  - Rebuilt in 1977
  - Built on top of naturally existing falls
  - Provided transportation for anthracite coal
  - Boaters currently use ‘slack water’ for recreation
- Canal originally provided
  - Means of transportation around rapids
  - Water power to mills on Venice Island

PA Canals



http://www.pa-canal-society.org/sites.htm


www.GlobeXplorer.com
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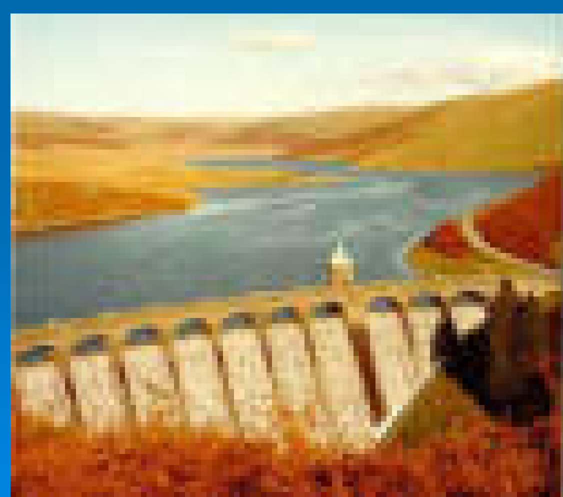
What we will be looking at…

- Environmental impacts of a hydroelectric power plant
- Economics
- Site assessment and compliance feasibility
- Design components

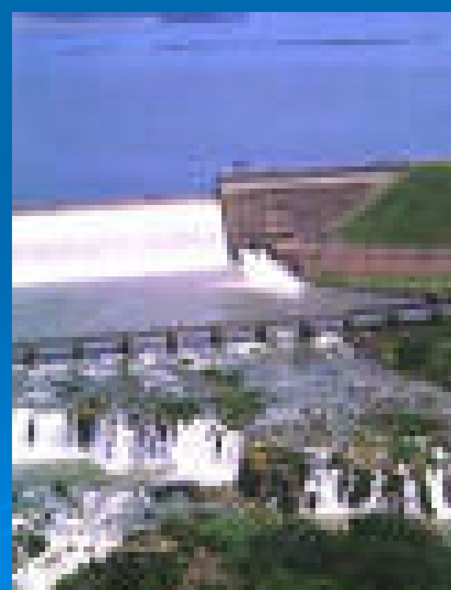
Wide Range of Effects

- Physical Environment
- Biological Environment
- Human Environment



Physical:
Land Use Change

- Creates a lake.
- Other land uses are lost. (forest…)



Sedimentation

- Sediment collects in reservoir.
- Clean, sediment-free water flows downstream.
- Enhanced erosion.
- Sediments don’t replenish river delta.

Construction Stage Disruptions

- New Roads.
- Local Fill-Material.
- Noise and Air Pollution.
- Environmental Guidance?

Climatic Changes

- Microclimate
- Moderation
  - Proximity to water
- Tropical Regions:
  - Reduce Convection-→ limits cloud cover
- Temperate Regions:
  - Steam Fog prior to freezing season

Earthquakes

- Not conclusive.
- Seismic activity attributed to creation of dams and adjacent storage reservoirs.
- Depth of water column appears to be the most important factor more so then total volume of water.

Biological:
Plant And Animal Life

- Loss of Habitat for both plants and animals
- Capture and Transport of Animals to safer grounds
  - Dangerous
  - Expensive
- Habitat conditions
  - The environment and living organisms need to deal with a change in flow rate and possibly temperature

Fish!

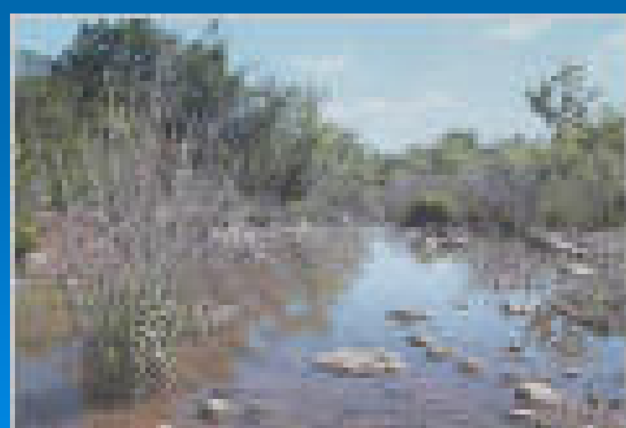
- Anadromous: Hatched in fresh water but live adult life in salt water. (Salmon)
- Catadromous: Hatched in salt water but live majority of adult life in freshwater. (Eel)
- Dam can block passage.
- Fish Ladders are not perfect.

Fish-Safe Plant

- Lower the number of fish passing through turbines. (screens and diversion passageways.)
- Reduce Gap size in turbines.
- Fish mortality is only 12% w/ Kaplan Turbines.
- Used on Columbia and Snake Rivers.

Aquatic Weeds

- Loss of Water.
- Competition with native species.
- Disease Rates.
- Control is possible but expensive.



Human:
Dislocation of People

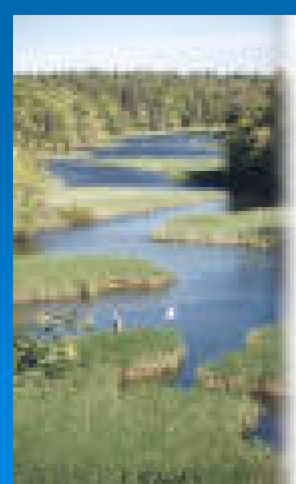
- Three Gorges Dam….1 million people!!!
- Many small villages are forced into one large community.
- Culture and beliefs left behind.

Environmental Benefits

- Pollution abatement
  - No greenhouse gas emissions
  - Cleaner energy source
- Flood control
- Irrigation
- Navigation
- Recreation
  - Reservoirs proved recreational benefits, like fishing and boating
  - Our site in particular is a major fishing area
- Constant water supply

Controversial Benefits

- Flood Control- 15 Million Chinese will benefit from the Three Gorges Dam.
- Recreation- Is a lake better then a free flowing river?



Understanding the Economics of A Hydroelectric Plant

Basic Economics

- distribution
- production
- consumption of services and goods

Financial aspects of a society on:

- local
- regional
- global scales

Hydroeconomics

- Developed or not?
  - Does a dam exist?
    - If not:
      - Land rights
      - Structures and improvements
      - Equipment
      - Reservoirs
      - Bridges
    - If so:
      - Structures
      - Improvements
      - Equipment

Development Costs:

-fish and wildlife mitigation
-recreation
-historical and archeological mitigation
-water quality
-fish passage

Flat Rock Economics

- Pre-existing dam
- Current recreational opportunities
- Historic Events
- Potential
- Ownership
  - BAMR

Should We Keep It?

Maybe, maybe not, but let’s examine what would result if the dam remained and a hydroelectric plant was built on-site.

Is it feasible to build a hydroelectric power plant at the existing Flat Rock Dam??

What we have to Consider:

- Landscape
  - Geologic features
  - Scenic attributes
  - Available Recreation
- Grid connection
  - Proximity to grid
  - Government permission to install utility lines
  - Public opinion

Considerations

- Wildlife habitat
- Fisheries
- River temperature control
  - Salmon do not feed in water < 7°C
  - No direct release from deep water

Considerations

- Acid rain
  - Release larger volume of water after storm if lime applied upstream
- Turbidity
- Historic and cultural sites

- Hydropower Consideration Factors
- What the consideration factors are

What the site looks like and what we’re working with

This will be a Multiple Purpose Project:

A water resource project may have multiple purposes, such as electricity generation, irrigation, flood control, recreation or environmental sites. These types of facilities must find an optimal balance between competing uses of water.

Construction

- Geology of land
  - Bedrock
  - Strength of surrounding rock
- Diverting Water
- Water pressure in stream
- Weather

Sizing the Hydroplant

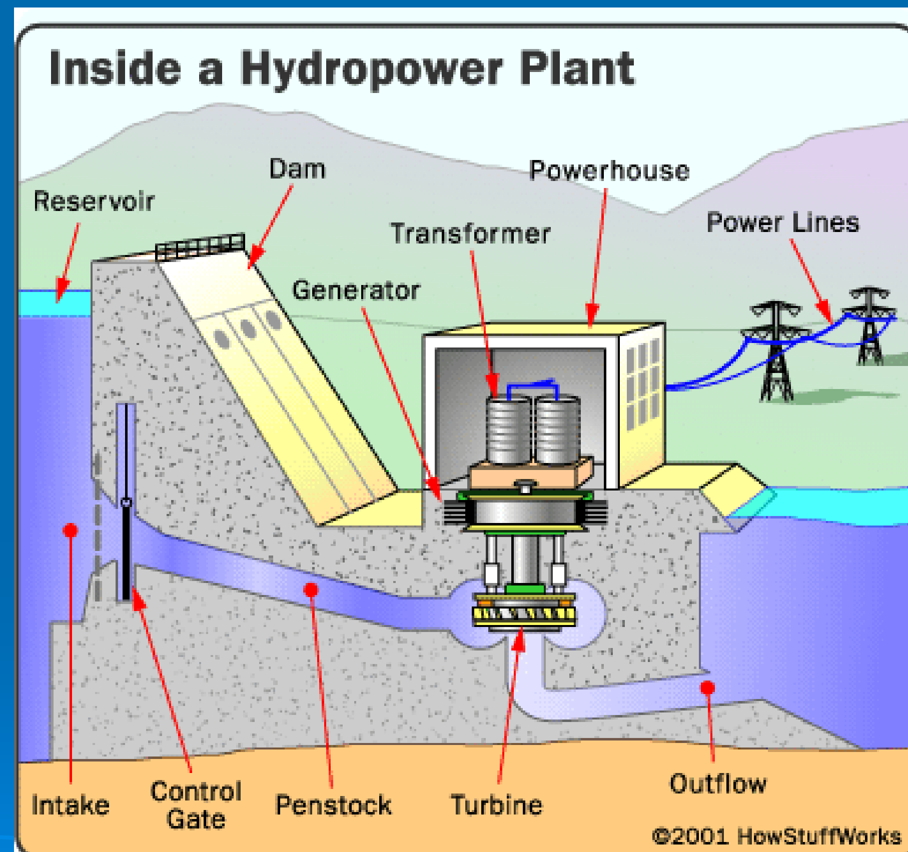
- Drop in elevation (head)
- Water flow
- Capacity needed
  - Peak
  - Average
  - Losses through transmission
- **COST**

Power, Energy

- Name Plate Rating: 2500kW
  - 2.5MW, therefore this is a small power plant
- One megawatt-hour is enough electricity to service about 1,000 homes for one hour
  - http://www.duke-energy.com/news/releases/2003/Jan/2003011501.html
- Manayunk Population (2000 Census) 19,000
  - http://www.philaplanning.org/data/nhbd/pash.pdf
- Average U.S. household size: 2.58
  - March 2002 (U.S. Census) http://www.census.gov/population/socdemo/hh-fam/cps2002/tabAVG1.pdf
- Therefore, Manayunk has roughly 7,364 homes.
- Enough power for 3.5 hours each day

Elements and Equipment used in the hydroelectric power plant

- Dam size
- Retention Basin
- Inlet valves
- Weir and control gate
- Penstock length/diameter
- Turbines
- Generators
- Transformers and excitation equipment
- Efficiency – head, heat, pipe losses



Sizing the Plant

- Drop in elevation (head)
  - We can achieve a drop of 21ft = 6.4m
- Stream flow
  - 9070ft^3/s = 256.83m^3/s
- Capacity
  - According to the INEEL hydropower resource database we can achieve 2500KW

We will only use part of the flow…but how much?

- Power equation: P=eHQg
  - P=electric power output in KW
  - e=efficiency (.81 for small scale hydroplants)
  - H=Head in meters
  - Q=design flow, m^3/s
  - g=gravitational constant, 9.81m/s^2
- Solve for Q
  - 2500=(.81*6.4*Q*9.81)
  - Q=49.15 m^3/s
  - %of flow used: 49.15/256.83=19%

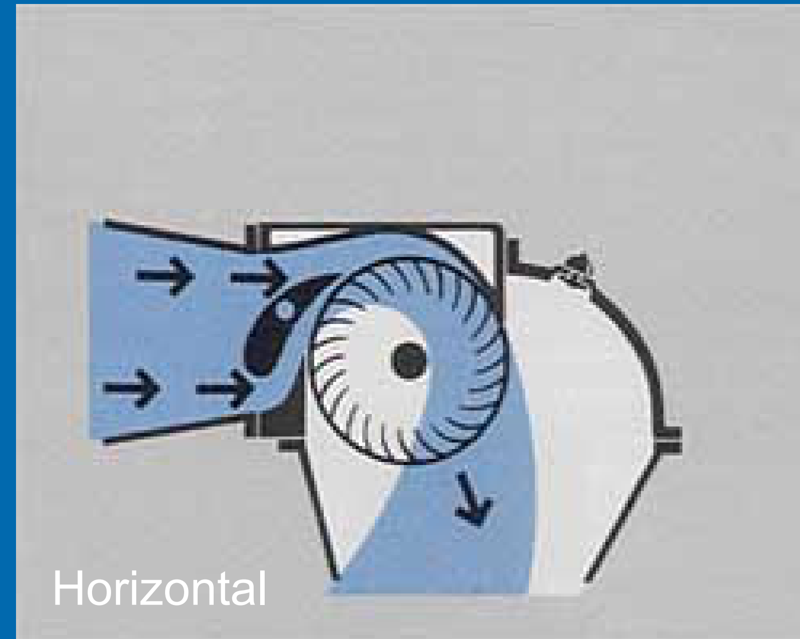
Choosing the Specs

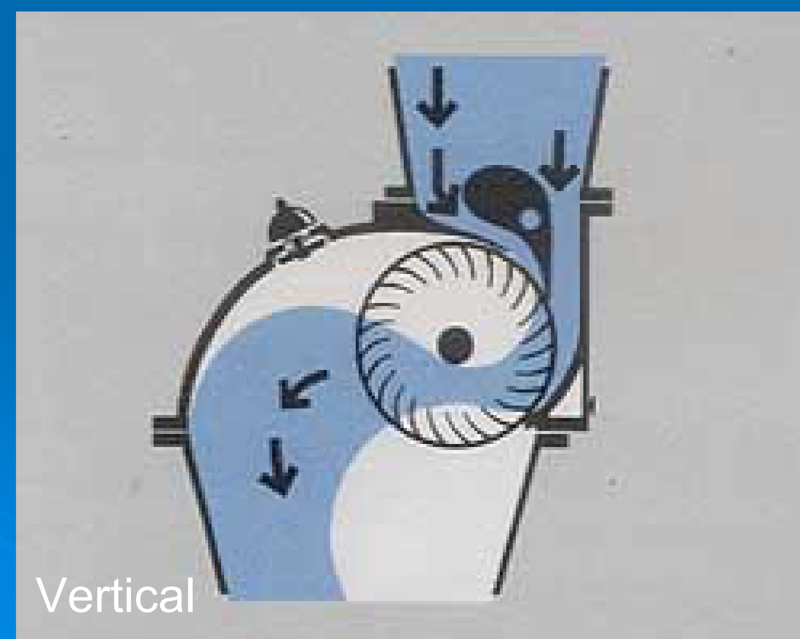
- Dam size:
  - The dam will be about the same height as the head, in this case 21 feet high
- Inlet valves
  - Major types are spherical (rotary), butterfly, and thruflow (pictured in order below)
  - We chose a thruflow as it has less head loss and leakage than the butterfly and spherical

- Intake Weir
  - 3 kinds
    - Side intake without weir
    - Side intake with weir
    - Bottom intake
  - We chose the side intake with weir
    - It will be the most effective and economic
- Penstock
  - Factors have to consider when deciding which material to use for a particular penstock

Turbines:

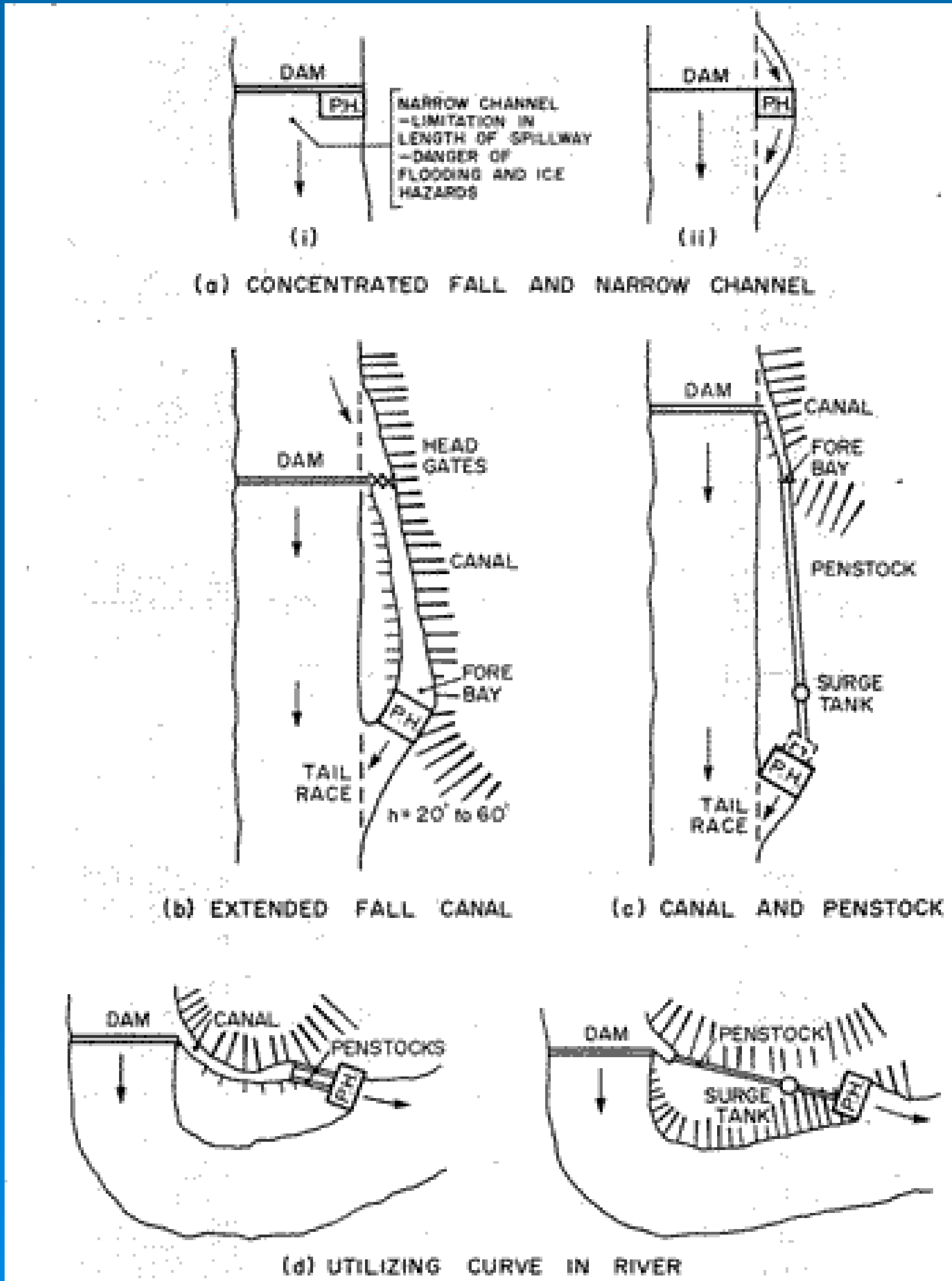
- Because we have fairly low head we chose to use a cross-flow turbine
- Ossberger turbine, efficiency=88%
  - Operating range: Heads: H = 1...200 m
    Water flows: Q = 0.025...13 m^3/s
    Power: N = 1...1,500 kW
  - Because of these specifications and our stream flow, we will need 4 turbines
- We will use the vertical model
- Ossberger turbines are relatively slow moving at 20-80 rev/min





Electricity Production

- Electricity is produced by a generator and is either sent to storage batteries or through the governor, transformer, circuit breakers, and protective relays before reaching the power line where it is distributed and utilized. These components are important for transferring electricity from the source to the end use, and in regulating the electrical operations and load of the system.
- Generators
  - Two types: vertical and horizontal
- Transformers



Development Configurations:

Based on how the dam and canal look now, design b, the extended fall canal looks to be our best option. That way we can best utilize our area.

Some other effects to take into consideration

Downstream

- Regulation of water must be considered
  - Inflatable dam
  - Reregulating pond

- Both meet peak use & avoid flooding

Hope

- *PR Newswire: PA Dept of Envr Protection press release, 6/11/99:*
- "The Flat Rock Dam in Philadelphia County, PA will soon have new fish ladders to help shad, striped bass, and other fish travel up the Schuylkill River. The dam, a 21 ft-high concrete gravity dam, was built in 1977 for recreation purposes. A budget of $21.8 million has been allocated for the project, which is estimated to bring in $2.5 million in fishing trip revenues once it's complete."

Oops… never mind.

- Pennsylvania Department of Environmental Protection Application 199901676-39
- **WITHDRAWN**
- 24 September 2001 FLAT ROCK DAM:

- http://www.nap.usace.army.mil/cenap-pa/CENAP-OP-R-4Q01.htm (Army Corps of Engineers)

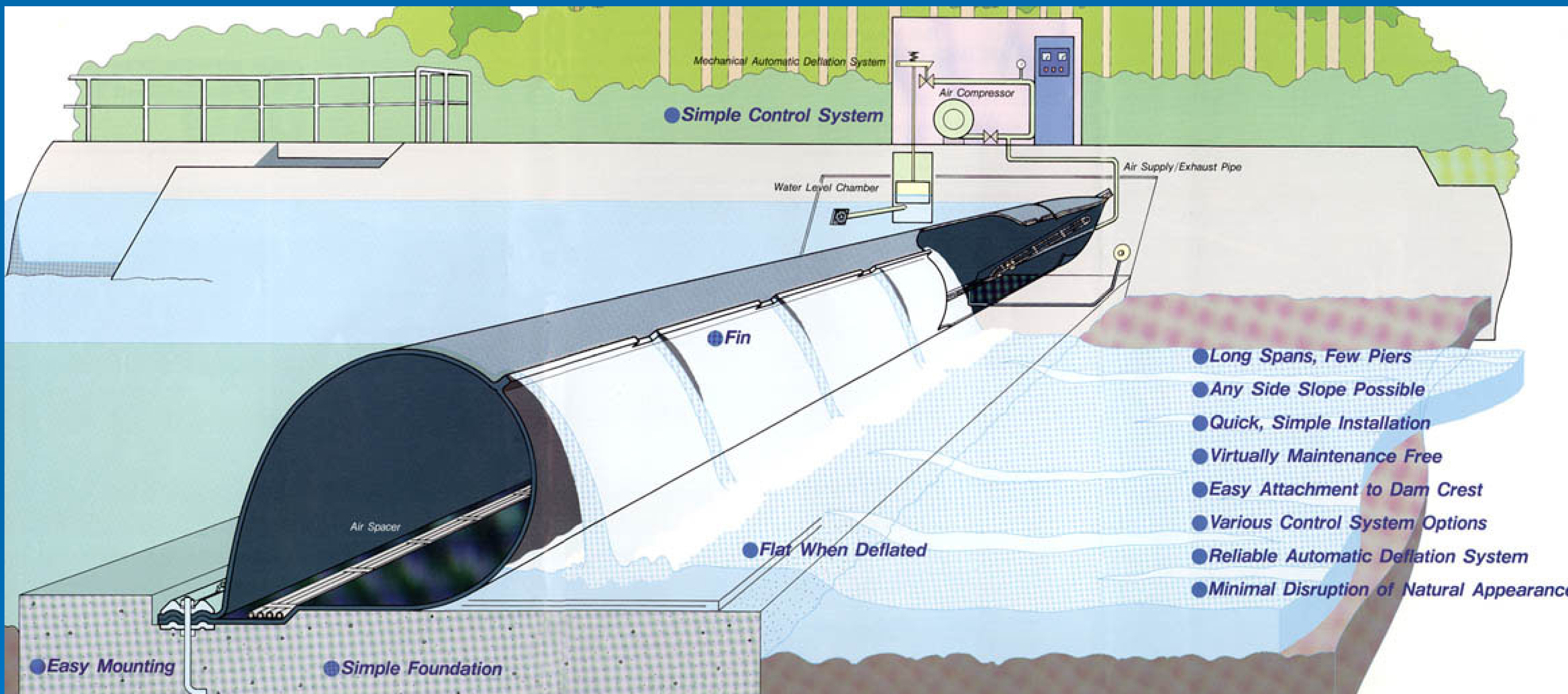
Happy fish

- PA Fish & Boat Commission
  - Press Release: September 2003
  - **Fish ladder is again being planned for Flat Rock Dam**

Water flow control

- Peak hours would result in less water over the dam
  - Water level changes above and below dam if flow is altered
    - Habitats altered
    - Solution needed
  - Ensure that the dam doesn't overdraw

Inflatable Dam



Inflatable dams have been constructed worldwide. The world's longest rubber dam was constructed in 1970 on the Susquehanna River at Sunbury, Pennsylvania. This dam has a total length of 2,100 feet and consists of six rubber tubes each 300 feet in length and one tube 175 feet long. The dam creates a seasonal recreational pool for boating and other water sports.

http://www.gannettfleming.com/damproject/02b_dam.htm

Inflatable Dams

- **The dams are made up of three main elements:**
  - a strong, flexible, rubber coated fabric tube which is fixed securely to a concrete base slab by clamping bars and anchor bolts
  - an operating system which controls inflation and deflation of the tube
  - and an automatic safety device which ensures tube deflation in flood situations.

Inflatable Dams

- From Science Daily:
  - Virginia Tech C E Ray Plaut Reports:
    - A key advantage of this type of dam, Plaut says, is that it can be deployed in a short amount of time, while a similar flood protection operation using sand bags would require much longer
- "Automatic sensors monitor the river level," Brozena said. "As the river rises and falls they adjust the level of the dam accordingly."

http://www.greenworks.tv/radio/todaystory/20020725.htm

Is it feasible? Is it a good idea?

- The dam already exists, so the building won’t be too disruptive and the flow will not be changed drastically
- It will provide power to the area while being environmentally friendly
- Since the dam already exists, economically it will be feasible as well
- So…yes, go for it!